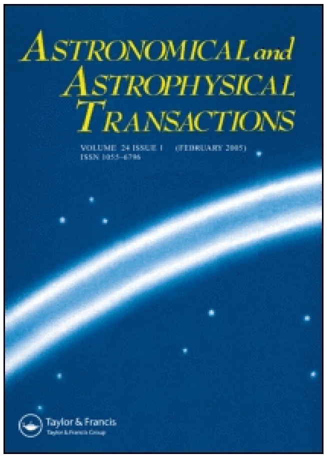

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Nonequilibrium states of a scalar field in quantum cosmology

Yu. A. Kukharenko [a]; R. F. Polishchuk [b]
[a] O. J. Schmidt Joint Institute of Terrestial Physics Russian Academy of Sciences, Moscow, Russia
[b] Astro-Space Center of P. N. Lebedev Physical Institute, Russian Academy of Sciences, Moscow, Russia

Online Publication Date: 01 June 1996
To cite this Article: Kukharenko, Yu. A. and Polishchuk, R. F. (1996) 'Nonequilibrium states of a scalar field in quantum cosmology', Astronomical & Astrophysical Transactions, 10:2, 143 - 145
To link to this article: DOI: 10.1080/10556799608203021
URL: http://dx.doi.org/10.1080/10556799608203021

Astronomical and Astrophysical Transactions, 1996, Vol. 10, pp. 143–145
Reprints available directly from the publisher
Photocopying permitted by license only

NONEQUILIBRIUM STATES OF A SCALAR FIELD IN QUANTUM COSMOLOGY

Yu. A. KUKHARENKO[1] and R. F. POLISHCHUK[2]

[1] *O. J. Schmidt Joint Institute of Terrestial Physics Russian Academy of Sciences, Moscow, Russia*

[2] *Astro-Space Center of P. N. Lebedev Physical Institute, Russian Academy of Sciences, Moscow, Russia*

(Received October 20, 1995)

Quantum cosmology was previously considered within the framework of the adiabatic theory only for vacuum short-wave fluctuations of the matter field. But the actual Universe is nonsteady, general equations of state of the matter field are nonequilibrium, and the matter tensor should be determined by averaging over an arbitrary nonequilibrium state. To describe such processes, Keldysh's diagram technique [1] extended to the case of curved space should be used instead Feynman's one.

KEY WORDS Keldysh's diagram technique, quantum cosmology, nonequilibrium state

The covariant description of a coupled quantum scalar field is given by the Tomonaga–Schwinger equation [2]:

$$\delta|\psi[t(x)]\rangle/\delta t(x) = \mathcal{H}_I(x)|\psi[t(x)]\rangle, \tag{1}$$

where $t(x)$ is a spacelike surface, the functional $\psi(x)$ is a field wave function, $\mathcal{H}_I(x)$ is a density of the scalar field selfinteraction Hamiltonian. For a derivative-free constraint, $\mathcal{H} = \lambda\varphi^4/4$. The field operators $\varphi(x)$ satisfy the known Klein–Fock equations. For the gauge conditions $g_{00} + \det g_{ij} = g_{0i} = 0$, the parameter $t = x^0$ is a harmonic function [3].

Based on the Tomonaga–Schwinger equation, one can construct the Liouville covariant equation for the density matrix of a coupling scalar field in curved space:

$$\begin{aligned} i\delta\rho[t(x)]/\delta t(x) &= \mathcal{H}_I(x)\rho[t(x)]\mathcal{H}_I(x), \\ \rho[t(x)] &:= \overline{|\psi[t(x)]\rangle\langle\psi[t(x)]|}. \end{aligned} \tag{2}$$

The solution of this equation is written in the form

$$\rho[t(x)] = S[t, t_0]\rho[t_0]S^{+}[t, t_0],$$

$$S[t,t_0] \;=\; T\exp[-i\int_{t_0}^{t}\mathcal{H}_I(x')\,d^4x]. \tag{3}$$

Here S is the evolution operator, T is the chronological ordering operator.

An arbitrary nonequilibrium state of the field is represented by a sequence of distribution functions and the field correlation functions. If the spectrum of a system is continious and the correlation functions are integrable in the momentum representation, these functions tend to zero for $t_0 \to -\infty$ [4]. The condition $t_0 \to \infty$ means that the times $t - t_0$ considerably exceed the relaxation time of short-wave fluctuations.

From this theorem on attenuation of initial correlations, the Wick theorem for free field operators follows:

$$\langle N\varphi(x_1)\ldots\varphi(x_n)\rangle_0 = \sum_{i_1\ldots i_n}\prod_{ij}\langle N\varphi(x_i)\varphi(x_j)\rangle. \tag{4}$$

The chronological products of any Heisenberg operators $TA(t)B(t')$, being functionals of $\varphi(x)$ averaged over arbitrary nonequilibrium state, may be written in the form

$$\langle TA(t)B(t')\rangle = \langle T_cA_0(t)B_0(t')S_c[t_m,t_0]\rangle. \tag{5}$$

Here $t_m = \max(t,t')$, A_0, B_0 are the functionals for free field $\varphi(x)$, T_c is a chronological ordering along Keldysh contour going from the initial surface $t_0(x)$ in the in-region to the surface $t_m(x)$ and back, S_c is the evolution operator along Keldysh contour. Denote the lower branch going from the past to the future by the "minus", the back one by the sign "plus".

Keldysh's diagram technique is based on introducing the matrix Green functions

$$iG^{SS'}(x,x') = \langle T_c\varphi(x)\varphi(x')\rangle, \tag{6}$$

where $S,S' = \pm$, $iG^{--}(x,x') = \langle T\varphi(x)\varphi(x')\rangle$ is the causal Green function, $iG^{++}(x,x') = \langle\tilde{T}\varphi(x)\varphi(x')\rangle$ is the anticausal Green function, $iG^{++}(x,x') = \langle\varphi(x')\varphi(x)\rangle$, $iG^{+-}(x,x') = \langle\varphi(x)\varphi(x')\rangle$ are the Whiteman functions averaged over nonequilibrium statistic ensemble.

Expanding evolution operator into a series and summing the diagram expansion of the Green function, we obtain the matrix integral Dyson equation

$$G^{SS'}(x,x') = G_0^{SS'}(x,x') + \sum_{S_1,S_2}\int_c G_0^{SS_1}(x,y)\Sigma^{S_1S_2}(y,z)G^{S_2S_1}(z,x')\,d^4y\,d^4z, \tag{7}$$

where Σ is a mass operator, $\int_c$ is taken over the Keldysh contour.

We have shown that the divergences in the terms containing a product of the mass operator Σ by the occupation number of the form $n_p\Sigma n_p$ for $t_0 \to -\infty$ can be summed, and the result is substituting the initial distribution function of quasiparticles $n_p(t_0)$ by an exact $n_p(t_m)$ at the current instant t_m.

The Green function satisfies the Dyson equation (7) containing an unknown function $n_p(t)$. The equation for the function is obtained as an additional condition imposed on the solution to the Dyson equation:

$$\partial n_p(t)/\partial t = [\Sigma, G]_-^{S=-,S'=+}. \tag{8}$$

As a result of renormalization, Σ and G are functionals of the exact distribution function of quasiparticle $n_p(t)$. Substituting them into (8), we obtain a closed kinetic equation for $n_p(t)$.

The particle entropy is shown to be conserved in the self-consistent field approximation. Thus, nonsteadyness of the Universe leads to an adiabatic rotation of the quasiparticle eigenfunction base, but does not lead to a change in quasiparticle nonequilibrium state population, which corresponds to the inverse process. In the collisional approximation the kinetic equation becomes irreversible in time. A quasiparticle collision integral leads to increasing the entropy. Nonstationarity of the gravitational field leads to actual transition from some states to others, which implies scattering of quasiparticles.

The calculation of the energy-momentum tensor following the perturbation theory indicates proportionality of this tensor and distribution function.

References

1. Keldysh, L. V. (1964) *Zhurn. Eksp. i Teor. Fiz.* **47**, 1512–1527.
2. Bogolyubov, N. N., Shirkov, D. V. (1957) *Introduction into the Quantum Field Theory*, Moscow.
3. Polishchuk, R. F. (1987) *Dokl. Akad. Nauk SSSR* **292**, 73–77.
4. Kukharenko, Yu. A., Tikhodeev, S. G. (1982) *Zhurn. Eksp. i Teor. Fiz.* **83**, 1444–1456.